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Fully coupled activated sludge model (FCASM): Model development

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ABSTRACT

A sub-microscopic mechanism model named Fully Coupled Activated Sludge Model (FCASM) about biological nutrient removal in the wastewater treatment process was developed in the present study. The functional organisms existing simultaneously in the activated sludge system were separated into eight groups, including aerobic heterotrophic organisms, nitrite reducing organisms, nitrate reducing organisms, ammonium oxidizing autotrophs, nitrite oxidizing autotrophs, non-denitrifying phosphorus-accumulating organisms (PAOs), denitrifying phosphorus-accumulating bacteria (DPB), and glycogen-accumulating organisms (GAOs). In FCASM, the interaction relationships of the eight functional microorganisms were taken fully into account. FCASM could model biological nitrogen removal via nitrite by splitting nitrification process and denitrification process into two-step reactions, and the autotrophs and denitrifying organisms were divided into two groups, respectively. What's important, FCASM included the anaerobic maintenance processes of sequential utilization of polyphosphate followed by glycogen for PAOs and DPB and glycolysis of the intracellular stored glycogen for GAOs.

1. Introduction

The activated sludge process is a complex system including many biological conversion and transportation processes. In order to control the biological processes effectively, mathematical models, which have been regarded as one of the most useful and powerful tools for development and optimization of wastewater treatment processes, are inevitably needed for the quantitative evaluation of the activated sludge processes (Salem et al., 2002). Since the ASMs were proposed by International Water Association (IWA) task group, mathematical models about the biological processes in activated sludge systems have been paid much more attention by the researchers in the world (Henze et al., 1987, 1995, 1999; Gujer et al., 1999). ASMs, which can provide us with a standard set of basic models, are of great importance in biological wastewater treatment processes. However, great disadvantage is that most of the model assumption neglected nitrite as the inermediate product, and the nitrification and denitrification process was assumed as a single-step process in the previous ASMs. Therefore, ASMs have been considered not to be appropriate for these situations in wastewater treatment process when considerable nitrite accumulates in the system because of the poor nitrification capacity, or the specific effluent nitrite limitation of the wastewater treatment plant (WWTP). There is, therefore, an indispensable need for the construction of separate models for the two-step nitrification and denitrification process. Great interestings on two-step nitrification models in wastewater treatment process have been increasing since 1990s (Andreottola et al., 1997; Marsili Libelli et al., 2001; Wett and Rauch, 2003). ASM1 and ASM3 proposed by IWA was enhanced respectively by Dosta et al. (2007) and Iacopozzi et al. (2007) through introducing two-step model for nitrification process and considering both nitrite and nitrate denitrification processes. In the enhanced models, denitrification was taken by facultative heterotrophic biomass through anoxic respiration either on nitrite or nitrate, and thus organic carbon was removed. But actually, the facultative heterotrophic biomass included nitrite reducing organisms and nitrate reducing organisms. Thus, these models could not describe denitrification detailedly and accurately.

Enhanced biological phosphorus removal (EBPR), which results from a group of organisms named phosphorus-accumulating organisms, has been widely accepted and regarded as one of the most economical and sustainable processes to remove phosphorus from wastewater. In 1980s, two extensively accepted mechanism modes for biological phosphorus removal were proposed in wastewater treatment process. One was Comeau and Wentzel mode, which was represented by the models of ASM2(d) (Henze et al., 1995, 1999) and ASM3-bio-P model (Rieger et al., 2001). The other was Mino mode represented by the TUDP model (Meijer et al., 2001, 2002). Based on the interaction mechanism between different microbial community, ASM3-bio-P model and TUDP model were improved by Sun (2006 and 2007). In these models, phosphorus-accumulating organisms, including non-denitrifying phosphorus-accumulating organisms (PAOs) and denitrifying phosphorus-accumulating bacteria (DPB), actually were just assumed as

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one functional group. However, the phosphorus removal mechanism of the two kinds of functional organisms is different. However, the phosphorus removal mechanism of the two kinds of functional organisms is different. For PAOs, acetate and propionate are taken up and stored in the cell as polyhydroxyalkanoates (PHA) under both anaerobic and anoxic conditions, and then PHAs are oxidized under aerobic condition. For DPB, acetate and propionate are absorbed only under anaerobic conditions, and then PHAs can be oxidized under both anoxic and aerobic conditions (Henze et al., 2002). As we can see, different behavior of PAOs and DPB exists under anoxic condition. Obviously, it will not be so suitable when these models are applied to describe phosphorus removal under anoxic condition.

In recent years, an increasing number of studies showed that glycogen-accumulating organisms (GAOs) could survive and proliferate under the alternating anaerobic/aerobic conditions in EBPR systems. The growth and proliferation of GAOs in EBPR system might make a nutrient competition with PAOs and DPB (Mino et al., 1995; Liu et al., 1996). Because of the existence and adverse function of GAOs in EBPR system, GAOs were then introduced into activated sludge models by some research fellows (Mino et al., 1995; Manga et al., 2001; Yagci et al., 2004; Whang et al., 2007). At the present time, most of the revised models were enhanced just by adding some biological processes of GAOs into ASM2(d). However, the theories of growth and decay for heterotrophic and autotrophic organisms are different from that for phosphorus-accumulating organisms and GAOs. In order to evaluate the significance of different endogenous processes in EBPR systems, many batch starvation experiments were carried out by Lopez et al. (2006). Results showed that anaerobic starvation was best described by maintenance processes. A sequential utilization of polyphosphate was followed by glycogen to generate maintenance energy while no significant decay of phosphorus-accumulating organisms was observed. Since polyphosphate cannot be stored in the cell of GAOs, the energy required for anaerobic maintenance is totally provided by the glycolysis of the intracellular stored glycogen (Filipe et al., 2001; Zeng et al., 2003a; Lopez-Vazquez et al., 2007). However, the endogenous utilization of glycogen for maintenance purpose was currently not represented in the available EBPR models. Therefore, the present study is to establish a sub-microscopic mechanism model for biological nutrient removal, named Fully Coupled Activated Sludge Model (FCASM), which describes the biological processes between macrocosmic and microcosmic field in wastewater treatments. The organisms that might exist simultaneously in activated sludge system were reclassified systematically and detailedly, and the interaction relationships among them were fully taken into account in FCASM. FCASM splited nitrification process and denitrification process into two-step reactions. The autotrophs and the denitrifiying organisms were also divided into two groups respectively, capable of modeling short-cut nitrification–denitrification. Moreover, PAOs and DPB were introduced into this model and were assumed as two functional groups to describe biological phosphorus removal. The most important is that the anaerobic maintenance processes that a sequential utilization of polyphosphate followed by glycogen for phosphorus-accumulating organisms (PAOs and DPB) and glycolysis of the intracellular stored glycogen for GAOs were included in FCASM.

2. Model description

2.1. Mechanism

Activated sludge system is a complex biological system including many different functional organisms and biological processes. The major eight known groups existed simultaneously in activated sludge system are aerobic heterotrophic organisms, nitrite reducing organisms, nitrate reducing organisms, ammonium oxidizing autotrophs, nitrite oxidizing autotrophs, PAOs, DPB and GAOs. Based on FCASM, the interaction relationships among the eight groups of microorganisms in activated sludge system were shown in Fig. 1. During the aerobic phase, dissolved oxygen (DO) is the main promoting effect for aerobic growth of all organisms with different oxygen affinity. It is much easier for heterotrophic organisms to obtain dissolved oxygen than that for the ammonium oxidizing autotrophs and nitrite oxidizing autotrophs in activated sludge system. Therefore, the heterotrophic organisms will grow much better than the ammonium oxidizing autotrophs and nitrite oxidizing autotrophs when organic substance concentration is high enough for microbial growth in the aerobic system. Firstly, ammonium is oxidized to nitrite by ammonium oxidizing autotrophs, and subsequently nitrite is oxidized to nitrate by nitrite oxidizing autotrophs. Biological denitrification is a microbial reduction process from NO_3^- to NO_2^- by nitrate reducing organisms and further to N_2 by nitrite reducing organisms. The nitrite and nitrate concentration is affected by the activities of the four groups of organisms. The nitrite will be accumulated when the activities of nitrite oxidizing autotrophs are inhibited, which will result in short-cut nitrification–denitrification. Firstly, oxygen concentration in aerobic system is one of the most important factors for nitrite accumulation. High oxygen concentration will promote the consumption of nitrite, while low oxygen concentration is an obvious disadvantage for nitrite production (Garrido et al., 1997; Pollice et al., 2002).

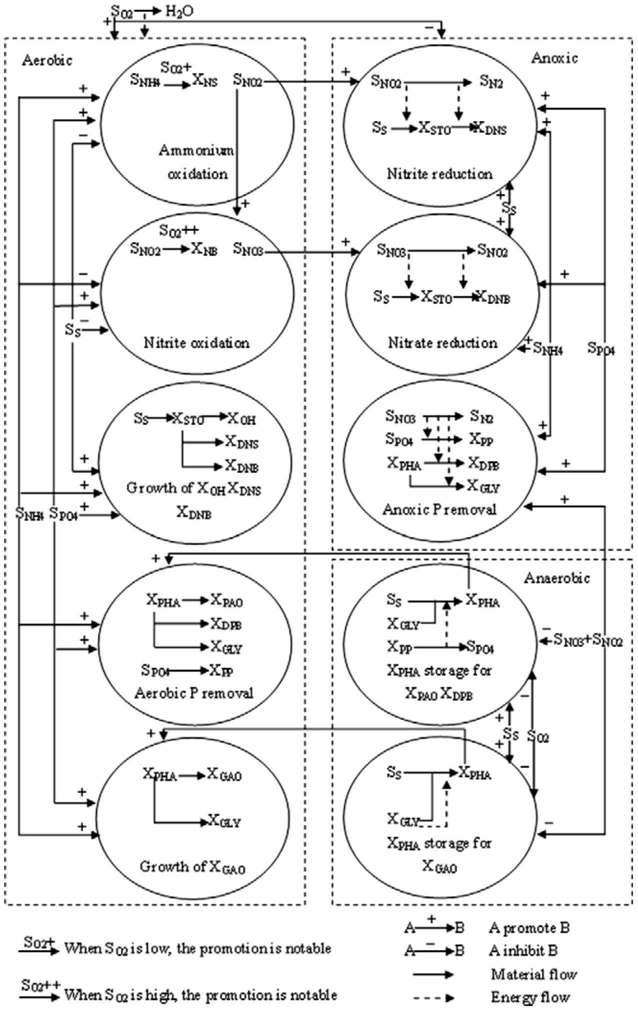

Fig. 1. Interaction relationships of microorganisms.